# Experimental Investigation of CI Engine Operated Micro-Trigeneration System Fuelled with Karanj Methyl Ester-Diesel Blend

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**Abstract.** A Micro-Trigeneration system based on Karanj Methyl Ester-Diesel Blend fuelled CI engine is designed and realized in laboratory. Experimental investigations are carried out to evaluate the performance and emissions of the original single generation system as well as the Trigeneration system developed. The test results show that the total thermal efficiency of Trigeneration reaches to 87.28% at the engine full load compared to only 33.21% for that of the original single generation. $CO_2$ emission in kg per unit (kWh) of useful energy output from Trigeneration is 0.1348 kg $CO_2$/kWh compared to that of 0.3184 kg $CO_2$/kWh from single generation at the engine full load. Percentage reduction in $CO_2$ emissions in kg/kWh with Trigeneration as compared to single generation throughout the load range is from 57.65% to 87.37%. The experimental results show that the idea of realizing a Karanj Methyl Ester-Diesel blend operated Micro-Trigeneration is feasible and effective to utilize the resources more efficiently.

## 1 Introduction

Increased energy demand, limited resources and the environmental pollution due to exploitation of energy, have emphasized the need for utilizing these resources efficiently. Trigeneration has been emerged as the effective technique for achieving the goal of energy conservation. It is more efficient and less polluting than electricity generated from central power plants. This makes Trigeneration the cleanest, most environmentally friendly and economic method to generate electricity.

Cogeneration is defined as simultaneous production of power and heat. Trigeneration is simultaneous production of power, heat and cooling or refrigeration. This is also referred as combined cooling, heating and power i.e. CCHP. [1,2] Trigeneration is advantageous over single electricity generation and cogeneration. It has higher total energy efficiency, lower emissions of CO2 and the other waste gases and it has more choices for useful energy outputs [1-15].

These systems range in size from large units designed to electrify and heat entire town, to small units that can serve a single home. In addition to the ability to utilize the by-product heat, Trigeneration also has the advantage of lower transmission losses and increased energy security from natural disasters, over

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consumption of power and even terrorist acts. Large industrial plants, universities, hospitals, and office buildings have successfully implemented Trigeneration systems. This technology is maturing and typically utilizes natural gas micro-turbines integrated with adsorption / desiccant coolers to take advantage of by-product heat in warm seasons. The new frontier of Trigeneration is in the residential and small building sector. Applying Trigeneration technology to smaller scale residential and small commercial buildings is an attractive option because of the large potential market. Many manufacturers are developing small scale Trigeneration systems or micro-CHP units. These small-scale power plants typically range in size from 1 to 15 kWe. These generators utilize an internal combustion engine, Stirling cycle engine, or fuel cell as the prime mover. Prime mover drives a generator which produces electrical power. The waste heat from the prime mover is recovered and used to drive thermally activated components such as an absorption chiller or desiccant dehumidifier, and to produce hot water or warm air through the use of heat exchangers. Fossil fuels are mainly used world over for providing energy to the prime movers. However the fossil fuels are depleting very rapidly. Moreover, the increased use of petroleum products will intensify local air pollution and enhance the global warming problems. This situation has compelled scientists and technologists in both developed and developing countries to look for economically and environmentally sound alternatives to fossil fuels. The vegetable oils can be used as an alternative fuel for the C. I. engines. Vegetable oil based fuels have been proved as potential alternative greener energy substitute for fossil fuels. The vegetable oils are renewable in nature and have comparable properties with Petro-Diesel. These are biodegradable, non-toxic, and have potential to reduce the harmful emissions. One of the best methods to use the vegetable oils in the diesel engine is the conversion of vegetable oil into Biodiesel by transesterification process. The transesterification process has been proved as the most effective method and widely utilized [16-20].

Several researchers have conducted experimental and simulation based investigations on Trigeneration systems [1-15]. Most of the studies are related to computational based simulation techniques or experimental studies on large scale Trigeneration systems [6,7,9,15]. Little work has been done in the field of experimental studies on Micro-Trigeneration systems utilizing alternate fuels for their prime movers. The investigations showed a significant impact on raising the energy efficiency and reducing greenhouse gas emissions responsible for global warming [3,4,8].

The objective of this study is to investigate the feasibility to develop a Micro-Trigeneration system working on alternate fuels and to carry out experimentations to investigate the performance and exhaust emission of the system. The Trigeneration system designed and realized in laboratory for the present research work is based on a CI engine as prime mover. Biodiesel-Diesel blend has been used as an alternate fuel for the CI engine. The waste heat from engine cooling system and engine exhaust system has been utilized to generate hot water through a heat exchanger and cooling or refrigeration through a vapor absorption refrigerator.

## 2 Experimental Setup and Procedure

The schematic layout of the experimental setup for the present investigation is shown in Fig.1. It consists of a test-bed, having a diesel engine, electric dynamometer, heat exchanger for heating the water, exhaust heat driven absorption refrigerator, fuel tank, air box, operation panel having controls and displays for different thermocouples, tachometer and flow meters. Fuel supply is measured using burette flow meter. NOx, CO, $CO_2$ and HC measurements were done with the help of AVL DITEST (AVL DiGas 4000 light) gas analyzer. Envirotech APM 700 Smoke meter was used to measure exhaust smoke. Calorific value of the fuel used was evaluated by Bomb calorimeter.

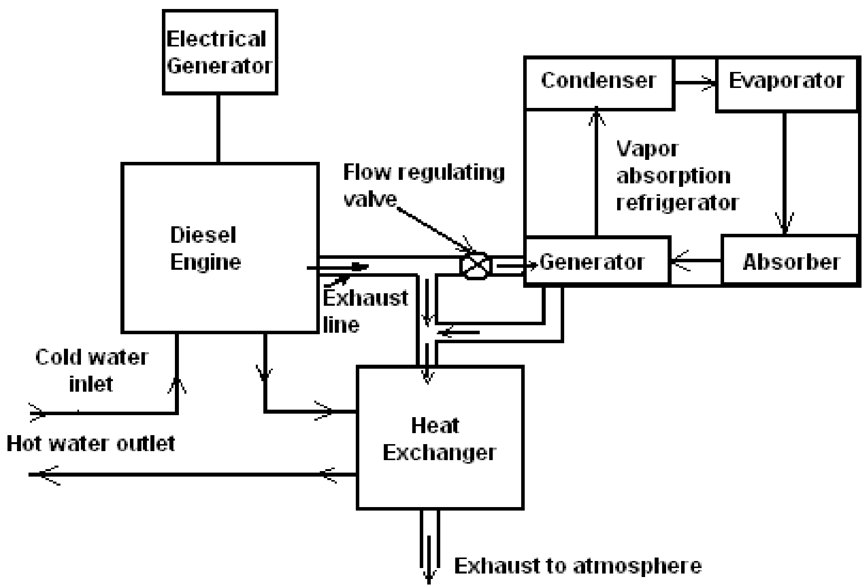



**Fig. 1.** Schematic layout of Experimental Setup for Trigeneration system

### 2.1 Diesel Engine Generator Set

A typical engine system widely used in the agricultural sector of India has been selected for present experimental investigations. A stationary single cylinder, four stroke, constant speed, water cooled, direct injection Kirloskar make diesel engine (Model-AV1) with electric generator was used for the experimentations.

### 2.2 Heat Exchanger

A heat exchanger was designed and fabricated for the experimental tests to recover heat from the engine exhaust gas according to the maximum heat output from the

exhaust gases. The heat exchanger is a cross flow, multi-flattened tube and finned, compact, and made of brass tubes and copper fins. The size of the heat exchanger designed was obtained as: Height 0.34 m, Width 0.3 m, Thickness 0.05 m.

### 2.3 Absorption Refrigerator

An Electrolux vapor absorption refrigerator was used for creating the refrigeration effect. It was a commercially available, $NH_3$-$H_2O$ pair based, electrically operated refrigerator with a capacity of 41 liters and heat input of 95 Watt. Generator of the refrigerator was modified to utilize the waste heat of exhaust gases. Due to small amount of heat available from the engine, the generator was modified to make the refrigerator, a direct exhaust fired refrigerator instead of a hot water fired or steam fired refrigerator. For the above purpose, a counter flow, double pipe type heat exchanger was designed, fabricated and installed.

### 2.4 Experimental Plan

A plan was designed for the experimental investigation of the performance of the Trigeneration system which is given as following:

#### 2.4.1 Performance of Engine Generator Working on Single Generation System

A series of tests were designed and conducted to evaluate the engine generator performance when it runs on a single generation system working on B-20 as well diesel for baseline data. The fuel used in the study is blend of diesel and Biodiesel based on Karanj oil which is an inedible vegetable oil and renewable in its nature. The botanical name of Karanj tree is Pongamia Pinnata. It is chiefly found along the banks of streams and rivers or near the seacoast of India. It is known that the pure vegetable oils create operational problems in engines due to its high viscosity and low volatility. So it was then decided to use Biodiesel of Karanj oil i.e. Karanj methyl ester as blending fuel in Diesel to obtain Karanj Methyl Ester-Diesel blend. The blend of 20% Karanj methyl ester and 80% fossil diesel by volume was selected as fuel for the existing diesel engine. The Biodiesel of the Karanj oil was produced by Transesterification process. The fuel blend so obtained is named as B-20. While varying the engine load between idle to full load the relevant data were recorded such as the engine generator power output, fuel consumption, engine exhaust temperature, emissions etc.

#### 2.4.2 Performance of Trigeneration

A series of tests were also designed and conducted to evaluate the performances of Trigeneration. In these tests, the engine load was varied between idle to full load (similar to that of single generation) and the required parameters were recorded in order to evaluate the total useful output (power + heat recovered from coolant and exhaust + refrigeration effect), total thermal efficiency etc.

# 3 Results and Discussion

The main physico-chemical properties of the selected fuel were evaluated and were found to be equivalent to that of fossil diesel. There was no abnormal combustion phenomenon in the engine and the engine was running smoothly. The performance and emission of the diesel engine with B-20 were nearly same as compared to that with fossil diesel. The diesel engine generator system fuelled with B-20, performed satisfactorily on the single generation system as well as on the Trigeneration system mentioned above. There was no engine operational problem during the experimentations. The test results for averaged values of three tests for each parameter are shown in the following sections:

## 3.1 Engine Generator Performance and the Comparison

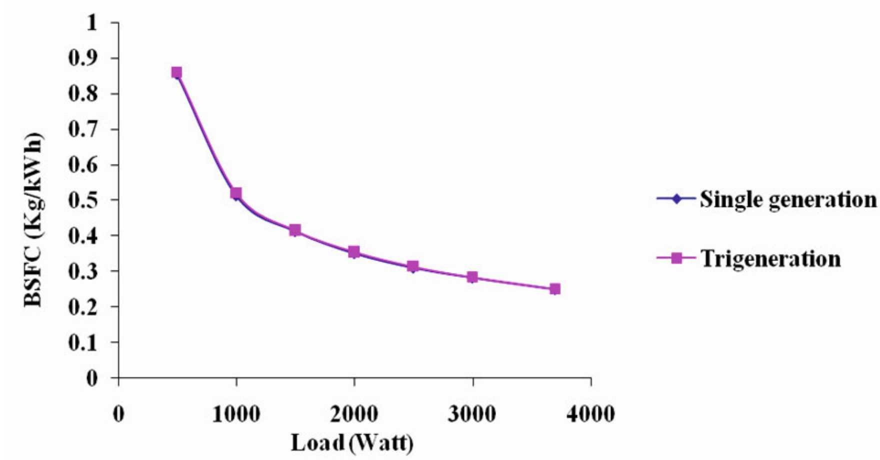
The test results for BSFC of engine generator on Single generation and Trigeneration systems are shown in Fig.2(a). The results show that the BSFCs of Single generation and Trigeneration are nearly equal. The test results for the brake thermal efficiency of engine generator on Single generation and Trigeneration are shown in Fig.2(b). The test results show that the brake thermal efficiency of engine generator on Single generation and Trigeneration are nearly the same. The results show that the integration of the Trigeneration components to the engine generator does not influence the performance of the engine generator significantly.

## 3.2 Engine Emissions

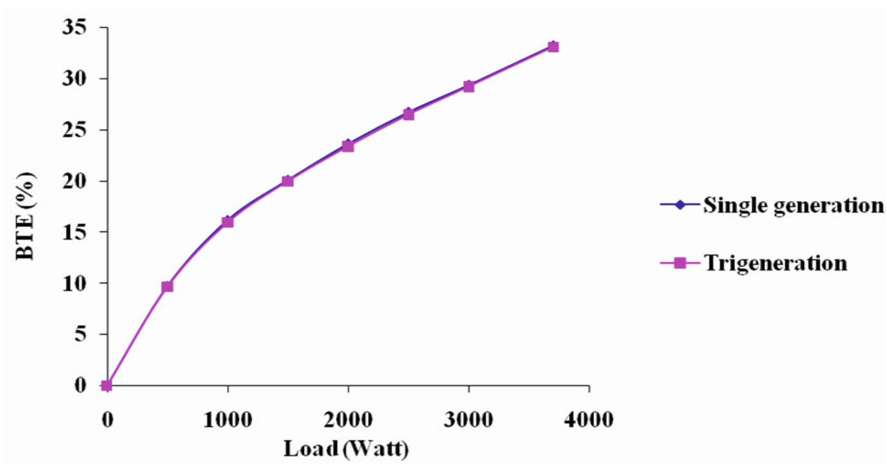
The emissions of smoke, CO, HC, NOx, and $CO_2$ from the diesel engine on Single generation and Trigeneration are shown in Fig.3. The results show that the differences are mostly very small.

## 3.3 Performance of Vapor Absorption Refrigerator

The parameters of the performance of refrigerator were recorded and evaluated during the Trigeneration operation on different engine loads. The test results for the exhaust gas fired refrigerator shows that at the full load, the generator temperature is $118^0$C. The final evaporator inlet temperature is $-3.2^0$C; at food chamber is $3.2^0$C. The heat input to the refrigerator $Q_G$ is 100.13W; the refrigeration effect $Q_E$ is 42.1 W; and the coefficient of performance of the refrigeration system is 0.4204. The test results for DC power electric heated refrigerator show that the refrigeration effect is 30.165 W with COP equals to only 0.3175. The refrigeration effect was calculated by placing a known quantity of water inside the food chamber and noting down the change in temperature of the chamber and time taken by it to reach steady state. The linearity of the fall in temperature was confirmed and UA value for the evaporator chamber was calculated to determine the refrigeration effect. These results show that the COP of the refrigerator driven by exhaust gas is higher than that of electric power heated refrigerator.




(a)




(b)

**Fig. 2.** Variation of (a) BSFC and (b) BTE with engine load and comparison of single generation with Trigeneration

### 3.4 Performance of Trigeneration System Compared to That of Single Generation System

The parameters of the performance of refrigerator were recorded and evaluated during the Trigeneration operation on different engine loads. The test results were validated by comparing it with the test results of experimental study on a small household size Trigeneration carried out by Lin Lin et.al [4]. Percentage changes in the values of performance parameters of Trigeneration over the single

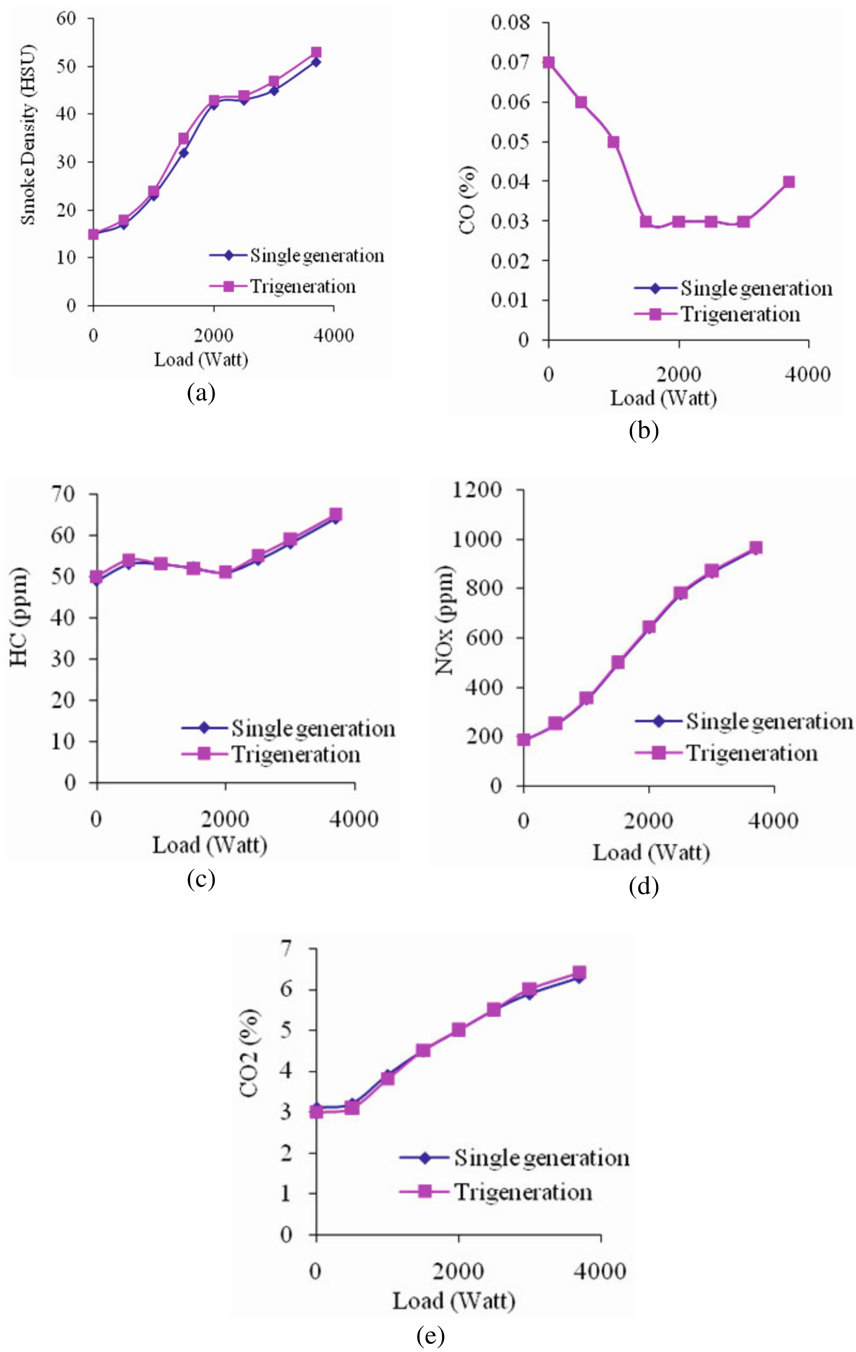



**Fig. 3.** Variation of (a) Smoke density (b) CO (c) HC (d) NOx and (e) $CO_2$ in exhaust with engine load and comparison of Single generation with Trigeneration

generation for the two studies are quite comparable. The detailed test results of the whole Trigeneration system from the engine no load to full load, are shown in Fig.4. From the figure, it can be seen that

- the useful energy output varies from 2370.06 W at the engine no load to 8873.23 W at the engine full load;
- the thermal efficiencies of Trigeneration varies from 52.13% at the engine no load to 79.38% at the engine full load;
- the specific fuel consumption varies from 0.1315 kg/kWh at the engine 500 W load to 0.1044 kg/kWh at the engine full load;
- the $CO_2$ emission varies from 0.1775 kg $CO_2$/kWh at the engine 500W load to 0.1348 kg $CO_2$/kWh at the engine full load.

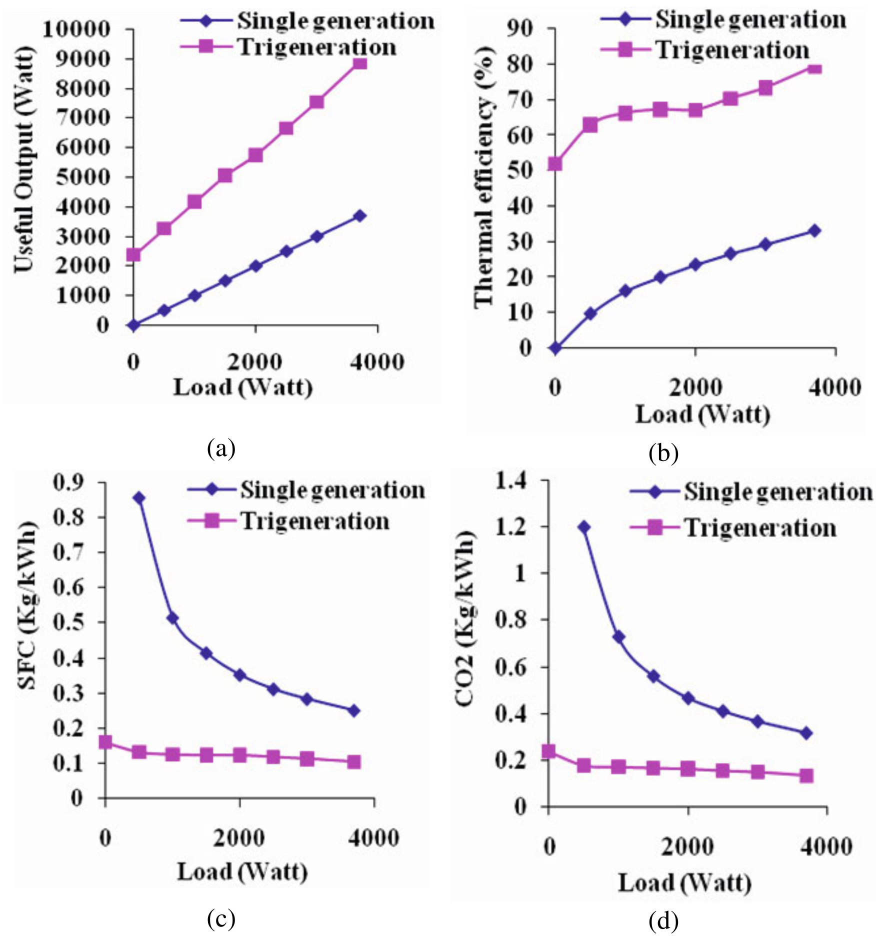



**Fig. 4.** Variation of (a) Useful energy output (b) Thermal efficiency (c) SFC and (d) $CO_2$ for Single generation and Trigeneration and their comparison

Fig.4 also shows the comparisons of the useful energy output, total thermal efficiency, specific fuel consumption and $CO_2$ emission between Trigeneration and single generation. From the results, it can be seen that the useful energy outputs from Trigeneration are much higher than that of single generation. The increase in useful energy output is 139.92% at the engine full load. The total thermal efficiency of Trigeneration is from 139.03% higher than that of single generation at full load. The fuel consumed by Trigeneration is much less than that of single generation. The specific fuel consumptions for single generation are from 0.8540 kg/kWh at the engine 500W load to 0.2497 kg/kWh at the engine full load. The decrease in fuel consumption for Trigeneration over single generation is from 58.16% at the engine full load. The $CO_2$ emissions for single generation are from 1.1968 kg $CO_2$/kWh at the engine 500W load to 0.3184 kg $CO_2$/kWh at the engine full load. The $CO_2$ emission per unit (kWh) of useful energy output of Trigeneration is reduced by 57.65% at engine full load, compared to that of single generation. This shows that the $CO_2$ emissions from Trigeneration are much lower than those from single generation.

## 4 Conclusions

In this study, performance and emission of a Micro-Trigeneration system based on Karanj Methyl Ester-Diesel Blend (B-20) operated CI engine are evaluated. The performance of the engine with B-20 is nearly equivalent to that with Diesel. When the engine generator runs as a single generation or in a Trigeneration, the brake power output, brake thermal efficiency and the fuel consumptions for the two systems, are nearly the same. The increase in useful energy output from the Trigeneration as compared to single generation is from 139.92% under different engine loads. The total thermal efficiency of Trigeneration is from 139.03% higher than that of single generation at full load. The saving of fuel consumption for Trigeneration over single generation is 58.16%_at full load. The $CO_2$ emission per unit (kWh) of useful energy output from Trigeneration is reduced by 57.65% as compared to that from single generation at full load. This research work shows that the idea of realizing a household size Trigeneration is feasible and the design of the Trigeneration is successful. The experimental results show that the Micro-Trigeneration is able to generate electricity, to produce heat and to drive a refrigeration system simultaneously from a single alternate fuel (B-20) input. The Trigeneration is more efficient, less polluting and more economic than the single generation.

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